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MODEL EXPERIMENT TO SEARCH FOR EMITTANCE GAIN OF RECIRCULATING HEAVY ION BEAM†

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We present a progress report on an experiment underway to measure the increase in emittance of a space-charge-dominated heavy-ion beam in passing through the Advanced Technology Accelerator (ATA) 30° bend "beam director." Thus far 7.5 μA of 8.6-keV Xe^+ beam has been injected into the upstream end of the bend and 4 μA survives to the downstream end. The loss can be explained by resonant charge exchange.

An experiment is being set up to search for an increase in emittance of a heavy ion beam in a circular ring; see Figure 1. The experiment uses the ATA "beam director," which was built to bend the 45-MeV ATA electron beam through 30° using permanent dipole and quadrupole magnets; see Figure 2. The ion source is a Physicon duoplasmatron producing about 50 μA of single charged Kr^{84} ions at 13.2 keV or about 20 μA of Xe^{131} at 8.5 keV. Upstream and downstream diagnostic chambers have been built to measure the emittance at the entrance to the bend and at the exit; see Figure 3. Each diagnostic chamber has two probes on sliding vacuum seals separated by 20 cm. The upstream probes have a "pepper-pot" hole plate or a phosphor plate. The downstream probes in each diagnostic chamber have a phosphor plate or a current-measuring plate. There are glass windows for observing each probe. There are two electrostatic lenses and horizontal and vertical steering plates to allow the production of a beam waist of variable diameter at either the upstream hole plate or at the entry to the bend. The upstream diagnostic chamber has a rotating disc with a hole to produce millisecond beam chops to search for time-transient effects due to neutralization of the beam space charge with electrons from ionized gas. The motor and pulley for the chopper can be seen mounted on the upstream diagnostic chamber in Figure 1. A gate valve leading to turbomolecular pumps is mounted on the bottom of the upstream diagnostic chamber. The holes in the pepper-pot plate have diameters of 7×10^{-3} cm. This was based on an un-normalized emittance estimated to be $\sim 3 \times 10^{-4}$ cm-rad, and the requirement that the self-force term in the beam envelope equation be one-tenth of the emittance term.

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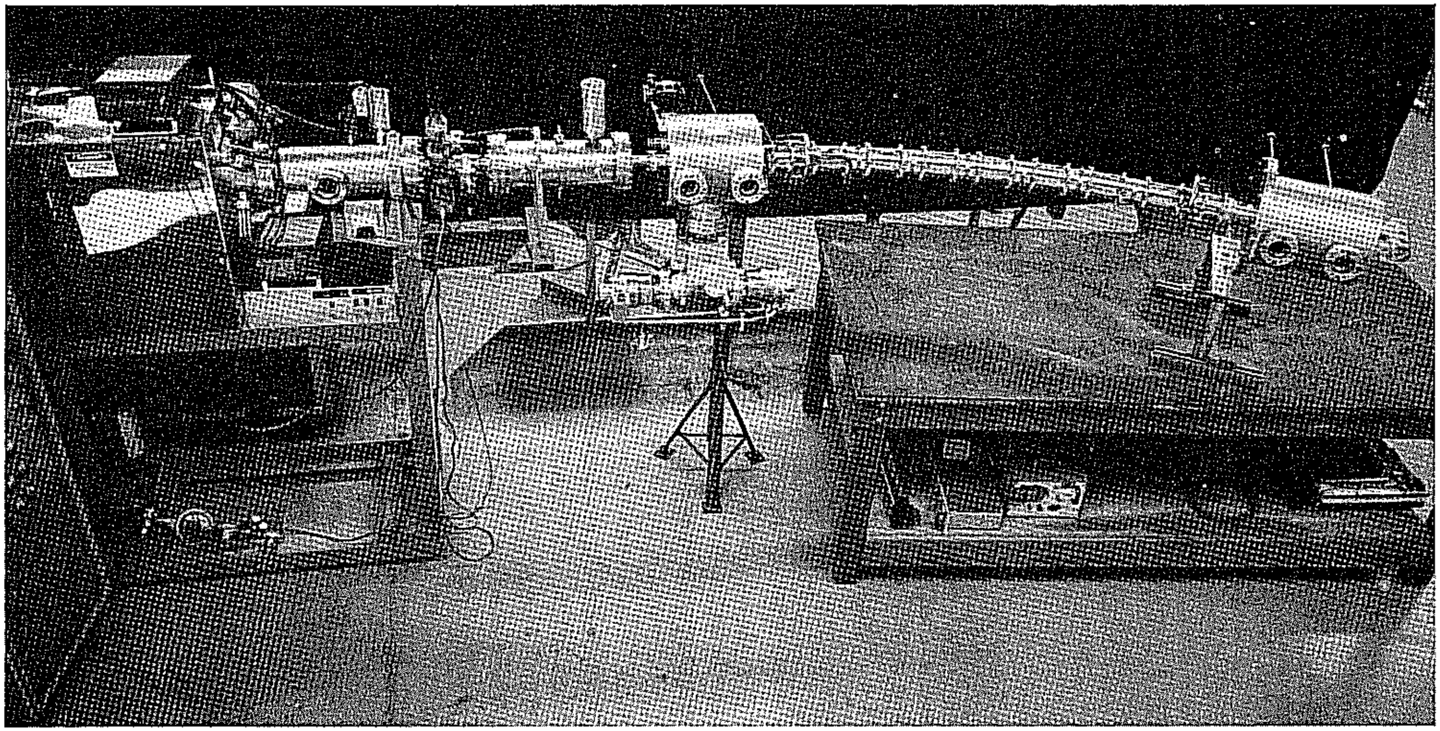

FIGURE 1 Photograph of the model experiment apparatus. The beam passes from the ion source on the left through two electrostatic focusing lenses and vertical and horizontal steering, the upstream diagnostic chamber, the 30° bend, and the downstream diagnostic chamber.

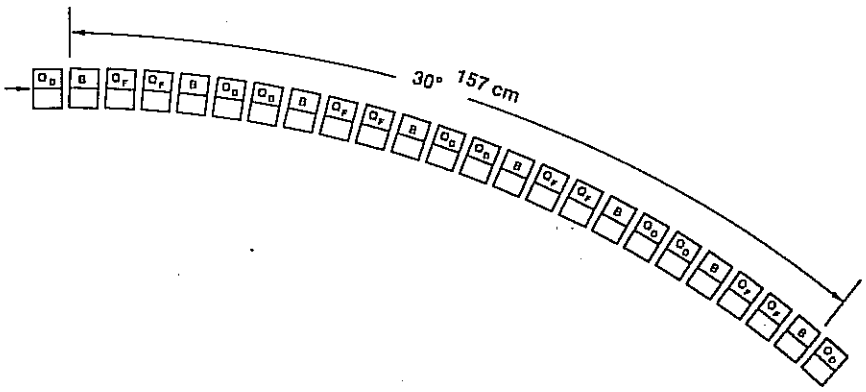

FIGURE 2 Magnet arrangement in the ATA beam director. The beam center of mass executes a 2π phase advance in passing through the 30° bend. The field of the bending magnets is 1.1 kG.

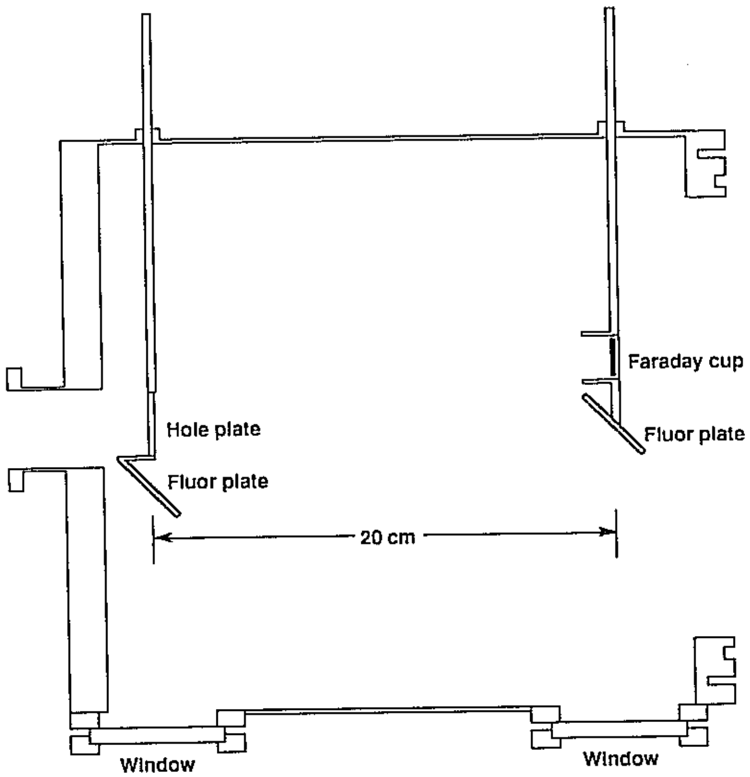

FIGURE 3 Diagnostic chamber for measuring emittance, beam size and current.

The tune, σ, is strongly depressed compared to the single particle tune, σ_0, in this experiment because of the relatively strong electric space charge potential ϕ (from the axis to the edge of a uniform density beam) and small expected un-normalized emittance ($\varepsilon \cong 3 \times 10^{-4}$ cm-rad):

$$\frac{\sigma}{\sigma_0} \cong \frac{U k_{\beta 0} \varepsilon}{\phi}, \tag{1}$$

where U is the particle kinetic energy divided by the electronic charge and $k\beta_0$ is the single-particle betatron wave number due to the external focusing. We expect to do the most significant experiment with about 50 μA of 13.2-keV K_r^+ ions for which $\phi = 2.58$ eV and $k_{\beta_0} = 4 \times 10^{-2}$ cm^{-1}. Then $\sigma/\sigma_0 \sim 0.06$.

Figure 4 shows measurements of beam current at the second probe of the downstream diagnostic chamber vs accelerating voltage. The focusing and steering were reoptimized for each data point. The largest current was measured at 8.5 kV, in satisfactory agreement with the prediction of 8.49 kV. Most of the beam missed the probe. This will be corrected in the future.

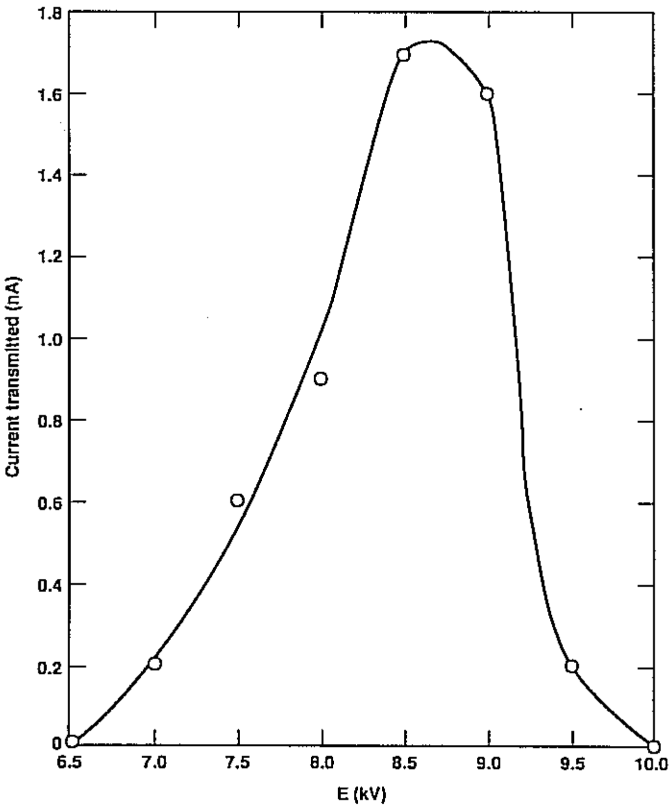

FIGURE 4 Xe^+ beam current transmitted through 30° bend vs accelerating voltage.

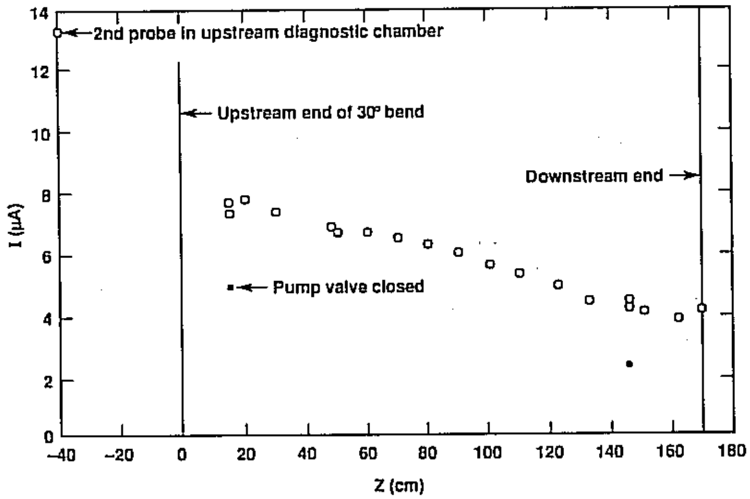

FIGURE 5 8.6-keV Xe^+ beam current measured at upstream diagnostic chamber and measured as a function of distance along the bend. The effect of closing the pump valve on the upstream diagnostic chamber is also shown.

In order to determine where beam loss was occurring, an electrically-insulated current-collecting disc was mounted on a sled and pulled through the beam tube of the 30° bend (Figure 5). The tube has an inside diamter of 2.8 cm. First the beam current was optimized on the second probe in the upstream diagnostic chamber; the measurement was 13.3 μA. When the probe was pulled back out of the beam, 5.5 μA was measured near the upstream end of the bend. Reoptimization of the focusing and steering increased this to 7.3 μA. At this point, the pump valve on the bottom of the upstream diagnostic chamber was closed. This caused the pressure (Xe gas) read on an ionization gauge located about 1 m upstream of the upstream diagnostic chamber to increase from 2.0×10^{-5} to 3.2×10^{-5} Torr. Simultaneously the beam current decreased to 4.8 μA. Upon the opening of the valve, the pressure decreased to 1.8×10^{-5} Torr and the beam current increased to 7.7 μA. The current decreased monotonically with distance (valve open), reaching 4 μA at the downstream end.

The beam loss is consistent with predictions for resonant charge exchange:

$$\mathrm{Xe}^{+}_{8.5\,\mathrm{keV}} + \mathrm{Xe}^{0}_{\mathrm{thermal}} \rightarrow \mathrm{Xe}^{0}_{8.5\,\mathrm{keV}} + \mathrm{Xe}^{+}_{\mathrm{thermal}}.$$

The cross section for 8.5 keV is about $\sigma = 5 \times 10^{-15}$ cm^2.[1] The Xe pressure (valve open) varied from about 1.5×10^{-5} Torr on the gauge mentioned above to about 5×10^{-5} Torr at the downstream diagnostic chamber. Thus about an e-fold loss is predicted for 200-cm distance. A pump will be installed on the downstream diagnostic chamber so as to minimize the charge-exchange beam loss.

We hope to measure the upstream and downstream emittance shortly.

REFERENCE

1. H. S. W. Massey, E. H. S. Burhop and H. B. Gilbody, *Electronic and Ionic Impact Phenomena*, Vol. IV (1974) 2772.